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A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

ELECTRICITY IN COAL MINING.

BY JOHN PRICE JACKSON AND FRANK F. THOMPSON.

The statements in this short paper on the use of electricity in mines refer especially to the mining of soft coal. Of the essential elements in operating such mines, two of the most important are: first, apparatus to obtain efficiently the rapid handling of the coal; and second, to do this with the least possible number of openings. These conditions have evidently been large factors in causing the application of electricity to such operations.

The applications of power to mines, which we wish to consider, are principally for, (*a*) lighting, (*b*) haulage, (*c*) cutting or drilling, (*d*) pumping and driving fans.

Systems.—The systems worth considering which are in use at present may be tabulated as follows:—

1.—Rope haulage, and steam for all other purposes.

2.—Electric haulage and compressed air for other purposes.

3.—Electric haulage and electricity for other purposes.

Various other combinations are, of course, used, but these three will serve the purpose, as representing well-defined types.

Rope Haulage and Steam Power.—In the past, this system has been the standard, and even yet in many portions of the hard coal fields has a very firm hold. Experience has shown rope haulage much inferior to electricity in point of working economy, as is now being illustrated by the continual substitution of electric for rope haulage now going on in the soft coal field.

The Mitchell Coal and Coke Company had two mines running for some time at Gallitzen, Pa., under exactly similar circumstances, but one using rope, the other electric haulage. It was quickly proven that the electric was far preferable.

Steam power for pumps and fans in the mines has likewise been shown by experience to have many faults. Timbers along which the pipes pass rapidly deteriorate. The piping is expensive to install and can only be kept in good condition by constant attention. If the lines are long they are a source of large loss of power by radiation and condensation, even when well covered. They are a nuisance in the mines because of their high temperature. The steam motors are expensive from the standpoint of repairs and attention. Steam cutting and drilling will in most cases prove unwieldly. Mines operated under this system are without suitable means of lighting, an important matter in rapid operations.

Electric Haulage and Compressed Air Power.—The Berwind-White Company's mines at Windber, Pa., furnish an excellent example of this system, and so far as known it has given complete satisfaction. This plant, which has now six mines in operation with an output capacity of 5,000 tons per day, is eventually to be increased to ten mines with 10,000 tons capacity. The haulage in the mines is done by electricity, while the drills, interior pumps, and fans are driven by compressed air. The use of compressed air has many obvious advantages. It is found that the machinery, working under the extremely severe conditions to be found in a mine, performs its duty well. It requires little attention and is thoroughly reliable. On the other hand, pipe lines in extended mines are expensive to lay and keep in repair. The pipes soon deteriorate and when the lines are removed from old workings it is usually found that much if not all the pipe is in too bad shape for further use.

The flexibility of the system, or its adaptability to quick changes, is not satisfactory.

Electric Haulage and Power.—For convenience in discussion this head may be divided into two sub-systems as follows:

(*a*) Direct currents for haulage and other power.

(*b*) Direct currents for haulage, and polyphase currents for other power.

The use of direct-current machinery for pumping and fans has not been found satisfactory in many instances. One large company after a thorough trial of such apparatus rejected it in favor of compressed air. The pumps in a mine are subject to only rare inspection and that, oftentimes, by unskilled work-

men. These conditions combined with the unfavorable location of the machinery will soon cause electrical troubles in the commutator, or elsewhere, of the most carefully constructed motor. Inasmuch as the stopping of a pump, even for a short time, may cause excessive damage, the use of such a motor is a constant menace.

The second electric system, that using direct and polyphase currents has the inherent disadvantage of requiring the installation of two distinct and separate sets of generators and wiring. That is a matter of serious importance as will be indicated later, but is neither so expensive nor cumbersome as the piping used for compressed air. The great advantage in the use of polyphase currents, lies in the fact that they permit the use of a motor that is perfectly reliable under essentially all conditions of operation to be met with in mining. This compound electric system seems without doubt to be the best that can be installed for large operations. It comprises the advantages of all the other systems while eliminating their most serious defects. A system using polyphase currents alone might possibly prove more advantageous, but would have the serious defect of requiring two trolley wires, and even if this difficulty were overcome it would have to await the development of a polyphase motor suitable for a mining locomotive.

The Davis Coal and Coke Company.—The Davis Coal and Coke Company's plant at Thomas, West Virginia, is so efficiently equipped with this compound electric service as to be worthy of a short description. The company operates two mines at Thomas, the Thomas drift and the Davis shaft, and one mine at Coketon, a drift.

The power station is a roomy brick building containing Ames 200 H. P. engine direct connected to a 150 K. W. 500-volt direct-current generator; two Atlas cycloidal heavy duty engines of 150 H. P. one of which is belted to a 100 K. W. 550-volt three-phase alternator, and the other to a 76 K. W. 550-volt direct-current generator. The last mentioned generator has been installed temporarily in the place of a second 100 K. W. three-phase 550-volt alternator which had been operated in parallel with the other three-phase alternator. This 75 K. W. machine is used to help the haulage generator.

The coal is hauled by horses from the "rooms" to convenient points where it is collected into "trips" of from six to

twelve "wagons." The inside haulage motor, a 14-ton G. E. T. M. M. 35, takes these "trips" and hauls them to a central point of the breast and there they are combined into larger "trips" of about 15 to 35 wagons and hauled to the mouth of the mine by another similar motor. Each of the haulage motors gives 3,500 lbs. draw-bar pull. At Coketon, two miles away, another 14-ton haulage motor is installed.

The alternating three-phase generator is used for operating three 10 H. P. induction motors for driving small pumps, one 5-H. P., one 10-H. P., two 20-H. P., and one 30-H. P. induction motors for operating elevators; one 5-H. P. induction motor for a car lift; and three G. E. chain coal cutters. The induction motors for driving the pumps are located at the foot of the side entrance both at Thomas and Coketon. One 10 H. P. induction motor connected to a pump having a 5-inch suction 250 ft. long, and a 4-inch discharge pipe 750 feet long, with a total elevation of 28 feet, pumping 106 gallons per minute, was tested and found to take 11,000 watts. Induction motors are also used for driving fans, and conveyors which carry the slack coal from beneath the screens to the bins where it is stored until needed to charge the coke ovens.

Haulage.—Electric haulage equipments have been so long in use as to be now in a thoroughly good state of development. Even yet, however, the following faults may be observed in some of the machinery: Poorly acting brakes, unwieldy arrangement of the various controlling levers and trolley poles, brake rods or other projections too close to the track, and unsatisfactory speed and power regulation. Although some of these seem of small importance, any one of them is apt to seriously interfere with efficient work. The brakes on a mining locomotive should be very powerful and quick acting; likewise the arrangement of motorman's seat, brake handle, controller and sand-box lever should be such that the motorman can control his machine with the greatest possible dispatch and ease. Locomotives have been placed in mines with absolutely no provision for the motorman, and others where the lever arrangements are so unwieldy as to make the quick control necessary to safe operation impossible. In large coal operations economy is often to a large extent dependent upon the rapidity with which the wagon trains can be moved. Heavy grades both in favor of and against the load are frequently to be found. In order to draw a large

load and make quick time, the design and control of the motor should be such as to give an unusually great draw-bar pull at low speed, and at the same time have points of comparatively high speed. This condition is not properly met at present by all of the mining locomotives in operation. In one mine, which has come recently under the writer's observation, a slightly different design and arrangement of control in the locomotive would permit the handling of much larger loads at a great saving.

The power-house load curves for haulage are naturally very similar to those of other electric railway work. Fig. 1 shows curves for three stations. Curve No. 1 was taken at the Davis Coal and Coke Company's mine at Thomas, W. Va., two 14-ton

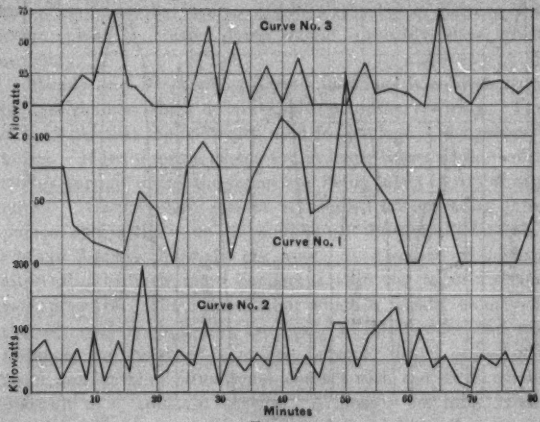


FIG. 1.

locomotives of 70 H. P. were in service hauling the regular output which in this case amounted to about 1300 tons per day. Curve No. 2 was taken at the Berwind-White Company's mines at Windber, Pa. Five locomotives of 12 and 20 tons are installed in this mine. Curve No. 3 was taken at the Davis Coal Company's mine at Coketon, Va. One motor of 14 tons was operating at the time.

Coal Cutting.—Under suitable conditions under-cut coal cutters will permit a great saving of labor, and therefore of expense, in soft coal mining. But in a large number of cases such cutters have been thrown out as unsatisfactory and have been replaced

by compressed air drills or other apparatus. In mines where curve veins abound they have ordinarily given much trouble. The cutter strikes the clay vein and sticks, or worse, bends, causing it to wedge tightly. This necessitates digging out with the pick-axe and expensive repairs. The most serious difficulty seems to arise from poor mechanical design and construction, combined sometimes with electrical faults. It should be possible to overcome these difficulties. In one mine where great trouble of this nature was previously experienced a new set of machines is now giving great satisfaction.

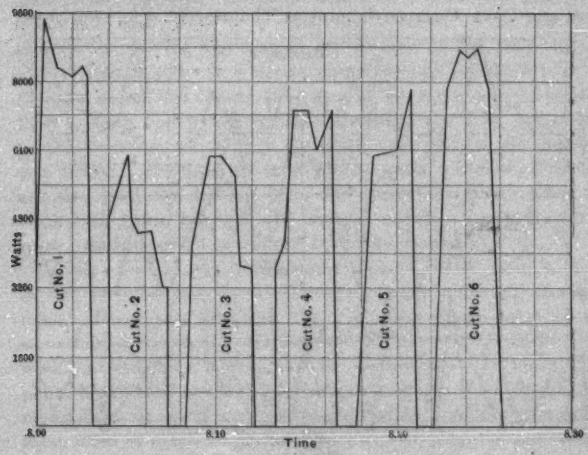


FIG. 2.

Figure 2 gives the power curve of a 20-H. P. cutter working in the mines at Gallitzen, Pa. In cases when under-cutters cannot be made to work, there seems no valid reason why electric drills could not be substituted, which would give as good service as compressed air, while at the same time preserving the valuable advantage of an all electrical plant.

Electric Pumps.—Electric pumps run by induction motors give very satisfactory service. The conditions met with in mining often necessitate frequent re-location of the pumps and in this respect the electric pump is by far the most satisfactory.

The attention required is certainly a minimum. A particular pump tested ran about ten hours per day, and the only attention required was that necessary for starting, stopping, and lubrication. Some mine owners have objected seriously to the electric pumps. In most cases these objections have been due to the compact arrangement of the pump and motor. In one mine which came under our observation, a 10-H. P. pump, which was bought with the motor, was replaced by the water end of a steam pump with a great improvement in the service. If electric motors were made to suit the pumps, and not the pumps to suit the motors, it would go far toward obviating the most serious objections. When the pump must be of large capacity and when it can be located within a reasonable distance of the steam plant, a steam pump would probably show greater economy.

Wiring and Pressure.—Wiring in mines is subject to certain restrictions which do not apply in ordinary wiring. There is no doubt that the 550-volts used for haulage is dangerous for horses. It is therefore customary in many mines to shut off the trolley current while the mules are being taken in or out of the mines. If a polyphase system is installed for operating cutters, pumps, etc., in the mine it should be run through the air courses and not through the main gangway. A pressure of 550-volts alternating is much more dangerous than the same direct-current pressure. The class of labor which is usually employed in the soft coal fields is of a low grade of intelligence, and many instances are recorded of serious personal injury or loss of life from accidental or intentional contact with the wires on both 500-volt A. C. and D. C. service. Although the mine laborers may have been repeatedly warned of the danger, they continue careless about the wires. When the mine roof is low enough to be reached by the men, the common practice is to run the trolley wire along one side supported by the usual hangers. When feeders are necessary they should be run along the same side. The other side of the roof should be kept clear.

Ordinary bare wire is preferable in mine work. The best insulation, rubber compounds, deteriorate rapidly under the action of the sulphur water. Any other insulation soon becomes inefficient owing to the moisture which is always present in a mine.

In large operations such as those at Windber, where 20 miles

of trolley are already in service, it is undoubtedly advisable to use at least 500 volts pressure for haulage. The polyphase power should preferably be used at a lower pressure for the sake of safety to employees. This could often be done without an undue expenditure of copper, by carrying high-pressure lines overhead to air ducts, or through unused passages to suitable points for distribution, where the pressure could be lowered by transformers. When it is necessary to run wires down a shaft through which coal is to be hoisted, the best practice would be either to to use lead covered cable, or wire which has been insulated with rubber, heavily braided, and drawn into an iron conduit having the ends hermetically sealed. In many instances when wires have been installed without such protection, in old shafts, trouble has resulted from the breaking of the wires, caused by lumps of coal falling down the shaft, etc.

Skilled Employees:—Too much pains cannot be taken to employ careful men as motormen for the haulage motors. The mine track is far from being up to the street railway standard. To haul a long trip of wagons over a bad track, requires careful handling of the motor. The motorman should be trained to study his track and his load, and know when and where to let his trip run slack and where to keep the couplings taut. A case came under the writers' observation where a careful motorman handled a trip of 15 loaded wagons, while another motorman stalled with 10 wagons on the same stretch of track. This matter is a very important one from the mine owners' point of view. The cost of driving gangways and shafts is considerable, and any method which will allow of an increase in the quantity of coal which can be taken from a single opening in a given time, adds very materially to the mine owners' profits.

Lighting and Signals.—As the lighting of a mine is a comparatively simple matter, it is scarcely necessary to consider it here. The universal method is to light up all switch points, and only other places of exceptional importance. In large mines using a number of locomotives, an efficient system of signals should be used in the main headings. This should be an automatic block system. Mr. A. S. McAlister of Windber, Penn., has worked out such a system, using incandescent lamps between trolley and rails, which is working admirably.

Efficiency.—The question of efficiency, from a fuel standpoint. is of comparatively small relative value, as the difference in

actual cost in fuel in the different systems is insignificant, when compared with other expenses. Data available seem to indicate, however, that the all-electric systems lead in this respect. As regards the total commercial efficiency, including maintenance, labor, interest, and depreciation, there can be no doubt but that the compound electric system using polyphase and direct currents, will give the best results.

General.—The data and statements presented in this short paper are gathered from personal experience in the mines, from mine superintendents, and from student thesis work carried on under the supervision of The Pennsylvania State College. In writing the paper, it was not intended to give a complete detailed treatise on the use of electricity in mines, but to outline the most important conditions and facts bearing upon such utilizations.

Discussion.

Mr. Elmer A. Sperry:—What few remarks I have to make are in the line of a plea for simplicity in electric coal-mining installations. The class of labor employed in and about a mine is such that absolute simplicity is necessary. In regard to accidents, I might say that up to two years and a half ago, I think we employed only 250 volts. At that time there had been no serious accidents recorded except to mules. But lately since the 500-volt potential has been used, the danger to life has become an important factor and especially since the polyphase has been introduced. That is especially vicious, and using it as has been attempted in various cases, where the metallic parts of the machine are connected, the motor in some instances is secured solidly to the frames of the machines and no insulation is possible, the bare metallic parts being directly in contact with the operators. Bare wires have to be used as has been indicated in the paper and the main lines are very poorly insulated all through. The drippings and constant breaking away of the roof and tearing down the lines render the insulation at best very poor, making it almost impossible to operate with a polyphase. Sometimes the trouble occurs unexpectedly in the middle of a cut. The men that are engaged in the operation are often superstitious, and the moment they commence to feel the current they back away and it is almost impossible to get a machine stopped or started or dealt with in any sense. I touch upon these matters as showing the difficulties engineers working along these lines have to contend with. I should say that the troubles with the pumps and with the constant current motors are largely those of overload. The motors installed early in the art were usually too light for the work.

Sometimes there is an accumulation of water and the pumps are too small to handle it, and the motors too small for the pumps. Sulphur water is a bad thing for a pump. As Prof. Jackson says if a pump could be made to stand mine service it would be a help. If the pump is new it is easy of operation but the corrosion increases and presently the action of the sulphur on the pump makes it work twice or three times as hard, and the friction factor of a deep mine pump with no suction is always great. The instance which is mentioned in the paper where air had to be substituted for electricity, was probably the fault of the motor being altogether too light for the work. I think for this class of service where infrequent attention is given to the apparatus, large motors ought to be used and run at slow speed, and ought to be capable of doing the work easily. I think that the complexity and the added expense of the double system mentioned should be entirely done away with. I do not believe that with proper proportioning and designing, there exists the necessity of such a system. And as I said, the most absolute simplicity is the great desideratum.

PROF. W. S. ALDRICH:—There is more promise of the application of electricity to coal mining in the development of new territory than of old. The prejudices do not exist in opening up new mines such as govern the continued use of equipment in old mines. Particularly important is the question of throwing aside old equipment, standing as it always does in the way of introducing the new electrical methods, however promising. While several changes in power transmission in mining operations have been brought about recently, they are chiefly confined to electricity and to compressed air. There is such a displacement going on, however, that at least one company has not installed a complete compressed air plant in the last four years. Electricity has been introduced successfully and it is practically the only means of transmitting power that has been introduced to develop abandoned coal mines. Lower veins have been thereby opened up that under the old methods were too expensive to work. Where working expense is limited, electricity is adopted. With regard to pumping, it is successfully performed by induction motors of course directly connected with centrifugal pumps or to triple-plunger pumps. The difficulties of electric pumping, however, are not entirely met by the induction motor, and one feature of this has been brought to our attention in this paper in the matter of standard sizes. There are engines in the market and there are pumps. There is no standard size of pump, no standard size of engine, of motor or of dynamo that will enable you to put such units together and have them work with best satisfaction. As long as each manufacturer has his own standards of fixed sizes there seems to be little hope of avoiding this difficulty. Professor Jackson says that in large pumps greater economy will be shown, but it is not stated whether these are to be of the ordinary direct-acting non-expansion type or whether they are to be of the more carefully designed triple expansion type. It is well known that the

ordinary direct-acting steam pumps consume anywhere from 120 to 300 pounds of steam per horse power per hour. The fact is that stationary compound and triple expansion pumps whether placed near or far away from the boiler, can be economically operated above ground; but these seem not to be capable in their usual arrangement below ground, of obtaining anything more than an economy from 20 to 30 pounds of steam per horse power per hour, corresponding to a duty of from 95 to 65 million foot pounds of work per million British thermal units. It would be a very poor electric installation that could not come up to that, even with a much smaller sized pump. It should be noted that the compound triple expansion pumps are in large units.

The largest of compressed air installations are now in use particularly in the anthracite fields where ventilation is so much needed. It has been found that mechanical circulation of air is better than to depend for ventilation upon air exhausts. In fact, it is better to get what you want directly than indirectly, better to have fans and a blower system than depend upon the exhaust from your air motors.

There is but one coal mining plant in West Virginia that is using at the present time a direct current 500-volt transmission, that of the Crozer Coal and Coke Co., Elkhorn, W. Va. The three-phase system has been installed, as far as the writer knows, at only five plants, namely: Columbia Gas Coal Co. at West Newton, Pa.; The Hutson Coal Compay, Deerfield, Ohio; J. W. Ellsworth & Co., Hartford, Ohio; Davis Coal and Coke Company, Thomas, W. Va.; Sterling Mining Co., Kennetta, Pa., and there have been no further alternating current installations since that of the J. W. Ellsworth & Co. eighteen months ago.

Mr. A. D. Adams:—It seems to me that in the eye of the average mechanical engineer the saving of a little or a great deal of copper occupies an undue space, and my observation of the application of electric power to industries is that there is too much of a tendency to run up the voltage. The difficulties of insulation are always with us, and we have sometimes found it better and often thought it better to put up with a rather larger investment in conductors, and a less investment in maintenance of insulation. I don't know much about coal mining but I think possibly that same state of affairs has a bearing upon that subject.

Mr. Sperry:—I think it would be safe to state an axiom that the miner's principal consideration of economy in the pump is to get there. He has to have something in this line that is absolutely to be depended upon and the matter of 60 pounds of coal or any other number of pounds referred to in this discussion is so far left by the other considerations that I think they need not be primarily considered in reference to mining pump installation. In some of the big anthracite mines it is simply a matter of shutting down the mine if water is not taken care of promptly. With the present scheme of "sumps" the matter of drowning out a pump is very unusual.

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

AIR-GAP AND CORE DISTRIBUTION.

The Magnetic Flux and Its Effect Upon the Regulation and Efficiency of Dynamo-Electric Machinery.—II.

BY W. ELWELL GOLDSBOROUGH.

The exact analysis of problems, the solution of which depends upon a knowledge of the actual distribution of the magnetic flux in masses of iron, seems to have received scant attention if we judge the present development of the design methods in use, by the writings of Essen, Kapp, S. P. Thompson, Hopkinson, Elihu Thomson, Ryan, and many more of our engineers who have instructed us so well in other and intricate matters pertaining to the efficient construction of electrical machinery.

The only reference to researches bearing directly upon this subject known to the writer was made by W. M. Mordey during his discussion of Dr. John Hopkinson's paper on the "Propagation of Magnetism in Iron" before the *Institution of Electrical Engineers*. He stated that some seven or eight years ago he made a test with the object of finding whether the penetration in laminated iron took place evenly over the whole area of the sheet. Although the length of certain paths of the magnetic parts was necessarily greater than others, he found the magnetic density uniform. He accounted for it by assuming that any tendency to a greater density in one place would be counteracted by the relatively stronger permeability elsewhere.

I am not informed as to the character of the apparatus which Mr. Mordey used in obtaining his results, nor am I sure that he performed his experiments with the end in view of investigating the subject from the standpoint from which it is taken up in this

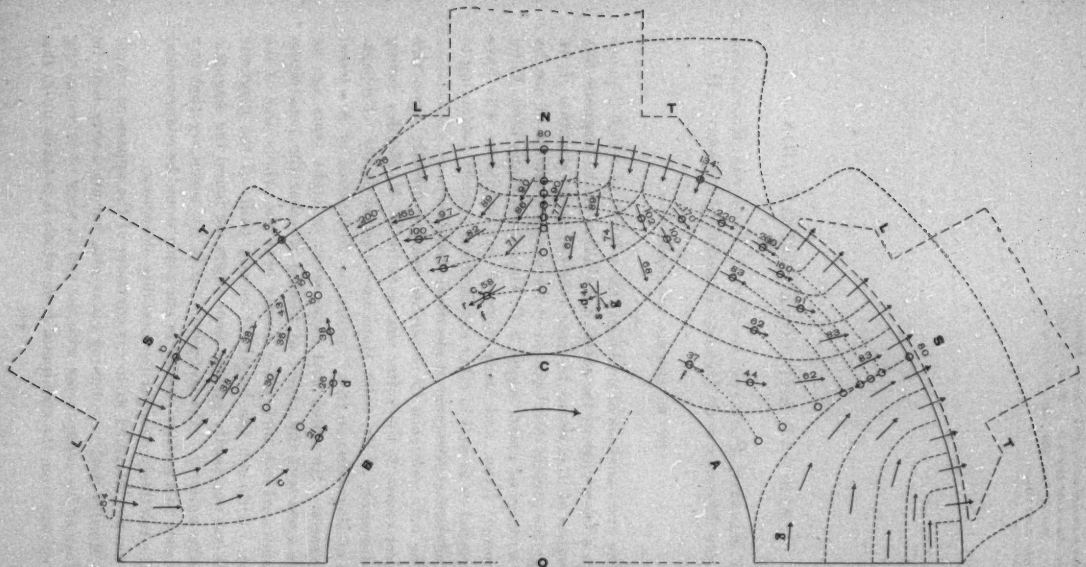


FIG. 1. Showing the calculated distribution of the magnetic flux in an armature core under three conditions *A*—The distribution due to the field ampere turns acting alone. *B*—The distribution due to the armature ampere turns acting alone. *C*—Distribution due to the combined action of the field and armature ampere turns. The numerals give the values of the flux density in centigausses.

paper. Certain it is, however, that all theoretical considerations point to the fact that, as used in electrical apparatus, laminated iron is not in general so placed as to warrant the assumption that there is an even and uniform distribution of the flux in planes at right angles to the direction of the flux paths.

In many instances where the iron is not subject to cyclic fluctuations in the intensity of the magnetic lines, variations in the density in planes at right angles to the mean path of the flux are unimportant; but is this true in the cases where masses of iron and steel are made to revolve in strong magnetic fields? or, where fields of flux are induced in masses of iron by coils excited from sources of alternating E. M. F.?

In discussing this matter, suppose we consider the condition existing in the armature core of a six-pole, 110 K. W., railway generator, a half-section through the armature and field ring of which is shown in Fig. 2. I have shown in section A, of Fig. 1, by the dotted curve extending across the pole-face, the air-gap distribution of the flux at no load. It is practically uniform over the pole-face owing to the toothed armature construction and the relatively narrow clearance space. Inasmuch as only a little over one per cent. of the total field ampere-turns are used in forcing the flux through the armature core and 73 per cent. is needed to force the flux through the double air-gap, the assumption that the surface of the armature under any pole-face is an equipotential area is admissible. The problem of determining the exact position of the flux-paths, and the density at various points in the plane of the section then resolves itself into a problem of dividing that portion of a lamina that lies between the center lines of two adjacent poles into paths of equal magnetic reluctance connecting equipotential surfaces.

The pole-face over section A, of Fig. 1 has been divided parallel to the shaft, into 10 equal strips, and these have been projected upon the armature surface as shown. The dotted lines joining the pole-faces through the armature show the dividing lines between the paths of equal reluctance. These paths have been determined by first equalizing their reluctance on the basis of a permeability of the iron of unity, and then making the necessary connection for the variations in the permeability of the iron with the varying densities by successive trial. Since each of the paths has the same reluctance and is influenced by the same M. M. F., acting at its terminal points, the same

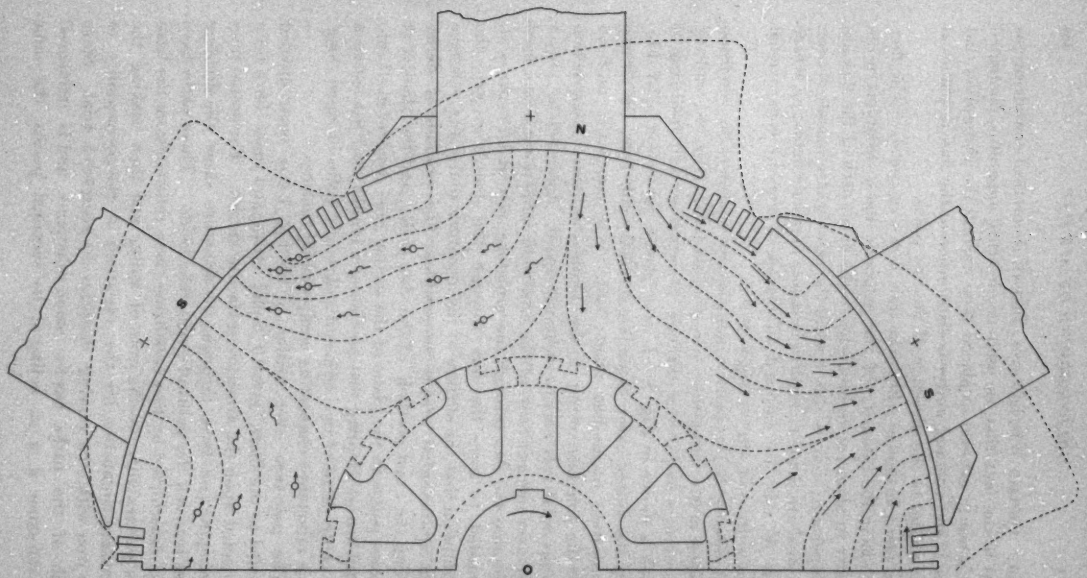
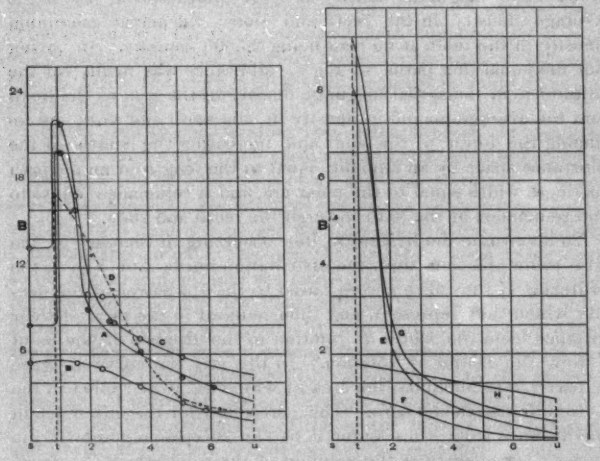


FIG. 2. Flux distribution in the core of an armature under full load conditions. Each path between pole faces as defined by the dotted lines, embraces the same number of gausses.

number of webers passes through each path and the number of gausses at any point on the center line of a path is equal to the flux per path in webers divided by the width of the path in centimetres at the point considered. The arrows drawn in section A, show the direction taken by the flux at as many points, and the numbers indicate the densities at the center of the arrows in centigausses. The magnetic density in the iron near the inner surface of the core on the dotted line between Sections A and C is a little less than 3,000 gausses while the density in the iron just below the teeth on the same line is a little over 21,000



PART 1. PART 2.

FIG. 3. Core Distribution Curves and Hysteresis Core Loss Curves.

gausses. At no load the flux paths are symmetrical about the section lines, except in so far as they are distorted by being slightly depressed under the leading pole tips L and raised under the trailing pole tips T as each molecule of iron is carried through the cycle of the hysteresis loop by the rotation of the armature. The arrows passing through the small circles indicate the points of maximum density in rings having radii equal to the distances of these arrows from the center O. In other words a molecule of iron is subjected to the greatest

magnetic stress when it passes under one of these arrows. The arrows are supposed to maintain fixed positions relatively to the poles, while the armature core rotates. Projecting the maximum density points of section A circumferentially on a radial line, and transferring them to Fig. 3, we obtain the curve A, Fig. 3, part 1. This curve shows the maximum core densities occurring in the iron at points having different radial distances from the center of rotation. The ordinates are expressed in kilogausses and the abscissae in inches. The distance $(s\text{-}t)$ is the depth of the slots; the distance $(t\text{-}u)$ the depth of the core iron below the slots. The magnetic density of 8,000 plotted over $(s\text{-}t)$ is the average density in the teeth and slots; the actual maximum density in the teeth at no load being 20,600 gausses. In laying out the equal flux paths of Fig 1, allowance was made for the difference in the actual magnetic density in the iron of the teeth and the average magnetic density in the teeth and slots, by reducing the depth of the slots and increasing the length of the clearance space by an amount equal to the length of an air path having a width equal to the polar arc, and a reluctance equal to the reluctance of the path through the teeth and slots.

To determine the hysteretic loss occurring in the part of the core below the slots from the distribution curve A of Fig. 3, the ordinates of the curve A were raised to the 1.6 power of the density which they represent, and then reduced in the ratio of their distance from the center of rotation to the distance of the point t from the center of rotation. In this way the curve E, figure 3, part 2, was obtained, the area of which is proportional to the hysteretic loss in the core. The correction for the difference in the distance from the center o of the successive points of the curve A is necessary as the volumes of the rings which the densities influence vary 54 per cent. between the outside and inside rings. We therefore find that with the distribution given in section A of Fig. 1, the core loss due to hysteresis will be 663 watts.

If we follow the usual practice[1] in making these calculations and assume that the flux in passing between the poles spreads

1. Dr. John Hopkinson, "Philosophical Transactions," of the Royal Society, May 6, 1886.
Gisbert Kapp, "Dynamos, Alternators and Transformers," p. 242.
S. P. Thompson, "Dynamo-Electric Machinery," p. 176.
Ryan and Macomber, "Sibley Journal," Jan., 1897, p. 125.

evenly over the core, the density in the core will be 7220 gausses and the core loss 492 watts, than which the value given above is 35 per cent. greater. (See curve H.) Apparently, therefore, if we admit the basis upon which these calculations have been made to be correct, the methods at present in use give erroneous results.

The discrepancy between the two methods, however, is greater than the considerations so far presented would lead us to suppose. In general it is assumed that if the total effective field ampere-turns impressed on the magnetic circuit are kept at a constant value, *i.e.*, if the difference between the armature back ampere-turns and the total impressed field ampere-turns is kept at a constant value, the armature losses, in the part of the core that is below the slots, will remain constant in value from no load to full load.

With a view to investigating this point, suppose we consider the effects produced by the cross-magnetizing armature ampere-turns when the field circuit is open and the armature coils are separately excited. Under these conditions, as shown in section B of Fig. 1, a field will be set up through the trailing pole-tip T, across the air-gap; through the armature core; and back across the air-gap, up into the leading pole tip, L. The ampere-turns acting to set up this field, will be zero about the center line of the pole-face, but gradually increase to a maximum under the pole-tips. The M. M. F. acting on the core paths between the two halves of the pole-face, will be proportional to the ampere-turns, and if paths be traced through the armature core, connecting points on either side of the center line of the pole-face and having a constant reluctance, the average flux density per path will be proportional to the M. M. F. impressed upon each path, and a balanced system of forces will be established in the armature core. The paths traced in section C have been calculated, with due reference to the permeability of the iron at different densities, to fulfil this condition; and the densities as indicated by the numbers over the arrows, have been determined as being the actual densities set up in the core by the cross-magnetizing ampere-turns. Owing to the fact that the M. M. F. acting on the longest path has the greatest value, the arrow points of maximum circumferential density all fall in this path. When these points are projected on the center line, and the values they represent transferred to Fig. 3, we get the curve B

which gives the values of the maximum densities through which the iron passes as it is revolved under the poles. In calculating the hysteretic losses that will take place in the core with separate armature excitation, we get curve F, obtained from curve B in the same way that curve E was obtained from curve A, and find that the core losses will amount to 174 watts.

Now to determine the distribution in the core at full load, when the total effective field ampere-turns are kept at the no-load value, we must combine the results already obtained and recorded in sections A and B of Fig. 1. This was done, and each of the arrows of sections A and B were properly transferred to section C, and the vector sums taken. As examples, vectors *f* and *c* were combined as shown to obtain vector *r*, and vectors *g* and *d* were combined to obtain vector *s*. Again it must be noticed, that vector *f* is numerically equal to vector *g* and vector *c* is numerically equal to vector *d*, but owing to the difference in the angular positions they assume when combined, vector *r* has a value 29 per cent. greater than the value of vector *s*. It is also interesting to notice that as the load comes on the machine, the density at the point *f* gradually increases, with constant effective field excitation, from 4400 to 5800 gausses at full load; and that an increase of 32 per cent. in the flux density at this point, has produced an increase of 55 per cent. in the core losses per unit volume for all iron at a distance *f-o* from *o*.

These same considerations apply to all the points in the armature core to a greater or lesser degree, and result in giving an entirely new distribution of the flux in the core. The points of maximum radial or circumferential density are also changed, and we find them located under the trailing pole-tip T of section C, in the upper part of the core, and under the the leading pole-tip L, in the lower part of the core. If we project the maximum density points upon the center line and transfer them to Fig. 3, we get now the curve C, the curve of maximum core densities at full load. Calculating the hysteretic losses, we get the curve G, and finally determine the full load loss to be 830 watts. Between no load and full load, therefore, while the total flux entering the armature per pole is maintained at the same constant value, the hysteretic loss in the core would seem to increase from 663 to 830 watts, or 25 per cent. And if the final value of 830 watts is compared with the uniform density value of 492 watts, we see the discrepancy in methods is

really much greater than at first seemed probable, being 69 per cent. instead of 35 per cent.

Of course these values refer only to the losses in the solid part of the core below the teeth. The hysteretic loss in the teeth at no load is 132 watts, and at full load 246 watts, owing to the change in the density under the strong or trailing pole tip; and an additional 27 per cent. must be added for eddy-current losses. The total armature core losses at no load are, therefore, 1000 watts and at full load 1370, and the real increase in the total core losses from no load to full load is 37 instead of 25 per cent.

The increase in the core loss with the load which these calculations show, probably accounts in part for the failure of many machines to come up to the expectations of their designers, and certainly presents an interesting field for speculation. With each change in the depth of the core, the core distribution of the flux changes. With each modification of the percentage of the armature covered by the poles it changes. With each modification of the armature winding, the distribution of the flux in the core changes. All these matters have a direct bearing upon the core losses, and are interesting as problems.

In Fig. 2 the results obtained in connection with Fig. 1 are displayed. The equal flux paths traced between the poles have been carefully located with reference to the full load flux distribution, and without reference to the direction of the vectors. It will be seen, however, that the black vectors on the right, which are the same as those of section c, Fig. 1, follow quite closely the direction of the paths as is to be expected. On the left of Fig. 2 the trace is shown of only the maximum density vectors, to the end of bringing out more clearly the effect upon the core-distribution of the armature ampere-turns. It will be seen that they have the effect of forcing the flux toward the bottom or inner periphery of the core under the leading pole-tips and of crowding it upwards toward the outer periphery of the core under the trailing pole-tips. Accordingly, the maximum density curve c of Fig. 3 has an area a number of per cent. greater than the area of a similar curve plotted from densities taken in a plane at right angles to the direction of the flux. In other words, the area of the curve c represents a greater amount of flux than really exists in the armature core.

The regulation of the machine here discussed is modified to

some extent by the effect of the saturation that occurs in the teeth and cast-iron pole shoes, so that the full load air-gap distribution is better than that shown in section c of Fig. 2, but for the sake of simplicity in taking up the subject for discussion, all modifying factors of this character have been eliminated.

With the end in view of obtaining experimental evidence of the correctness of the method of determining core losses that has been outlined above, two of my students, Messrs W. T. Hensley and E. B. Kirk, constructed a special piece of apparatus. As

View of Apparatus.

shown in the illustration contained in this paper it is an electromagnet, resembling as much as possible one pair of poles of a multipolar dynamo with a section of the armature. The armature is of rectangular form. As the flux divides to right and left under the pole face of a multipolar machine each pole of the magnet was made to represent half a pole of a dynamo.

The magnet is built up of thin plates of transformer iron, .015″ thick. Working drawings of the magnet and its parts are shown in the plates following.

The core and armature are made up of 180 of these laminations held by two side plates, each of the same surface dimensions, but 3-16″ thick. The whole is fastened together in both

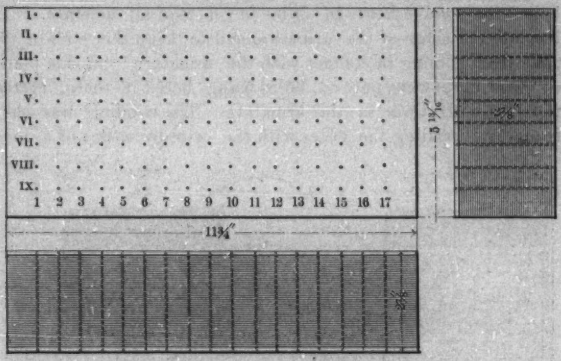


FIG. 4. Armature of apparatus used to determine the distribution of the magnetic flux in laminated iron cores.

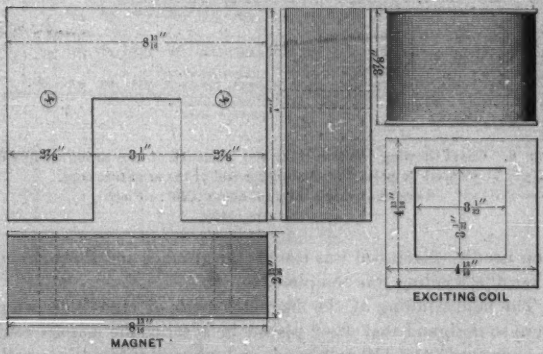


FIG. 5. Field yoke of apparatus used to determine the distribution of the magnetic flux in laminated iron cores.

armature and core by means of rivets.

A series of holes were bored in the armature, perpendicular to the side faces. They are .089″ in diameter and placed in rows

at right angles to each other, 5-8″ apart either way. Exploring coils of five turns each were wound in each pair of holes, making 29 conductors in each pole. Double silk covered wire was used.

Before winding the armature it was placed in a coil oven and baked for twelve hours in order to rid it of all moisture. To insulate the sides of the armature and to keep the ends of the coils from coming in contact with the armature iron, side plates of wood fibre were put on, holes being bored in them, corresponding with those in the armature. The winding was then made by threading the holes with the wire by means of a long

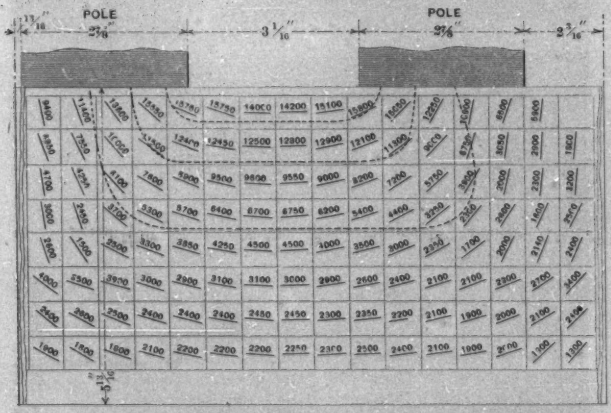


FIG. 6. Chart showing the direction and intensity of the armature flux developed by poles placed at either end of the armature core. Length of single airgap, about .015″. Field ampere-turns, 1405.

slim needle. Each coil was tested for grounds and short-circuits when the winding was completed.

The field winding of the magnet consists of eight coils which were so designed that when placed in a series the magnet could be energized from 110-volt mains and when connected in parallel it could be used with as low a voltage as 7.5.

As it was very necessary to know the exact area enclosed by each exploring coil, the distance between the edges of the holes was accurately measured. The exact area was then determined, where the holes were not parallel, by finding the area of the par-

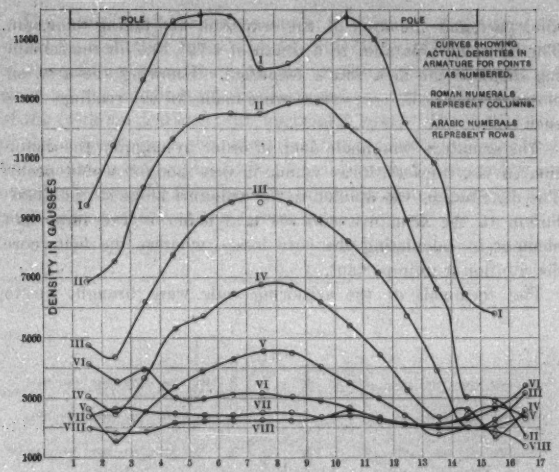


FIG. 7. Distribution of flux in armature when excited by poles placed at either end. Length of single airgap about .015'. Field ampere-turns, 1405.

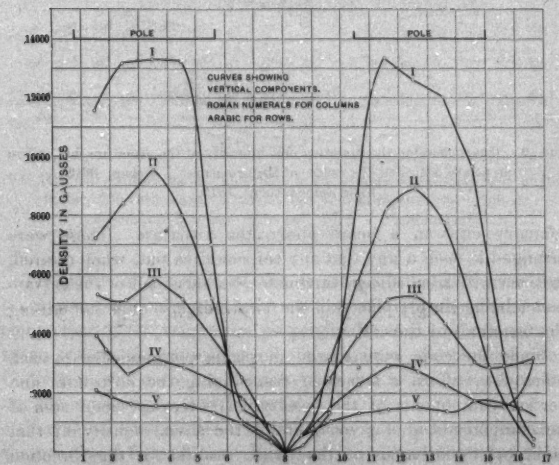


FIG. 8. Vertical components of flux in the armature when excited by poles placed at either end. Length single airgap, about .018". Field ampere-turns, 1405.

allel part and the area of the trapezoid and taking their sum. The holes were parallel to a depth of 1.72″, but for the remaining distance the area was a trapezoid. Knowing the area enclosed by each coil, corrections were made for the readings from each coil.

The armature was made deep in order to magnify the distortion of the lines of force which it was thought would occur. The distribution was studied in the armature alone as the distribution in the armature core of a dynamo is the important element in calculating the core losses, whereas the field core distribution is unimportant.

The terminals of the exploring coils were brought up to

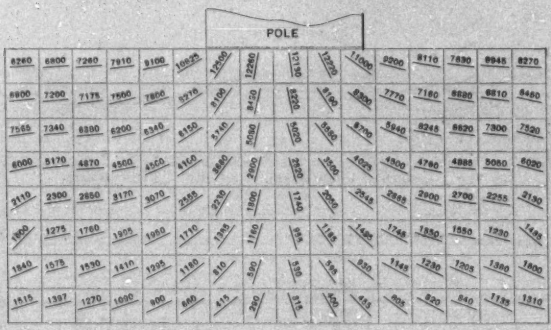


FIG. 9. Chart showing the direction and intensity of the armature flux, when one pole is acting at the center of the armature. Airgap, .0612″. Field ampere-turns, 1875.

mercury cups in a board above the armature. These were arranged in such a way that any coil could be put, when desired, in series with a ballistic galvanometer, the terminals of the galvanometer being simply placed in the two mercury cups containing the terminals of the coil.

Since the coils were wound in planes perpendicular to each other they afford a means of determining the horizontal and vertical components of the density. Hence, the vector sum of the components at a given point is the actual density at that point and the direction of the vector resultant is the direction of the flux at the point.

The intensity of the magnetism at the center of the area enclosed by each four holes was determined by taking the mean of the readings from the (n)th and $(n-1)$th vertical coils and the mean of the readings of the (m)th and $(m-1)$th horizontal coils of the (y)th vertical and (x)th horizontal rows. The vector sum of these means gives the intensity at the point considered, and unless the curves for the horizontal and vertical components are extremely irregular from point to point, the method gives a very close approximation to the correct value.

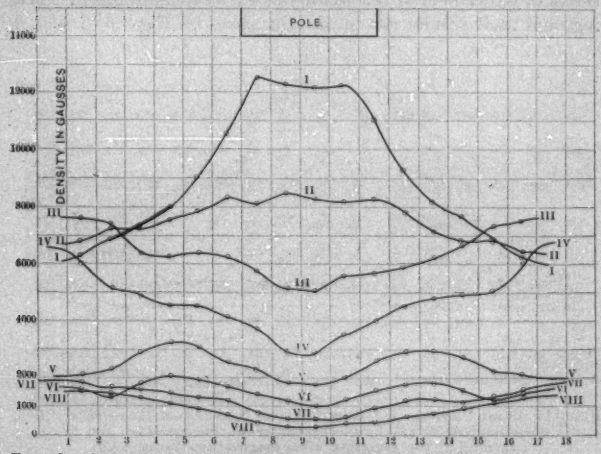


FIG. 10. Curves showing actual density in the armature, with one pole at the center of the armature. Plane of field yoke at right angles to plane of armature laminae. Air-gap, .0612". Field ampere-turns, 1875.

The width of the face of the armature in contact with the poles was practically the same as that of the poles, hence the component of the magnetism perpendicular to the side faces was taken as zero, since the sides of the armature are parallel also. Correction was made for the distortion due to the holes containing the exploring coils as follows:

The actual area enclosed by a square having for its vertices the centers of four of the holes was found and the side of the equivalent square was determined. Then the ratio of the actual

distance between the inner sides of the two holes from one another to the side of the equivalent square was taken as the correcting multiplier for the holes.

Correction for lamination was made as follows:

Weight of armature if solid, 24655.3 grams with wrought-iron at 480 pounds to the cubic foot.

Actual weight of armature, 21437.64 grams. The ratio of these weights, .87 is the proportion of iron in the armature.

The gentlemen who constructed this apparatus also obtained a series of experimental records under various conditions of working, and their results are shown in part, in Figs. 6, 7 and 8.

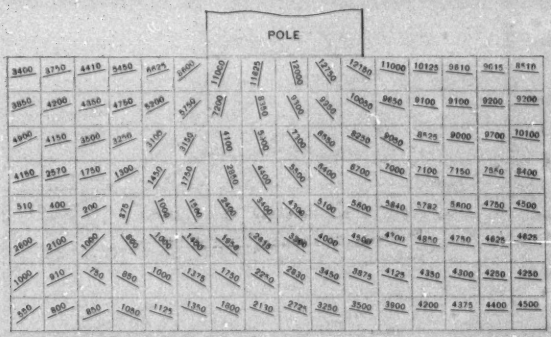


FIG. 11. Chart showing the direction and intensity of the armature flux, when one pole is acting at the center of the armature and influenced by the armature cross-magnetizing turns. Air-gap, .0613". Field ampere-turns, 1875. Cross-magnetising ampere-turns, 540.

The experimental work was completed by Messrs. F. Maze and C. Williams, during the past spring, and some of the results obtained by them are shown in Figs. 9, 10, 11, 12, 13 and 14.

The results, as they are presented, indicate so clearly the conditions which obtained in each case, that it is hardly necessary for me to add a word in explanation.

Fig. 8 is directly comparable with section A of Fig. 1. It represents the conditions existing in a machine in which the poles cover 65 per cent. of the armature, however, instead of 80 per cent., as in the case of Fig. 1, and differences are noticeable accordingly. For instance, the curve of maximum density

distribution for Fig. 8, is plotted as curve D, Fig. 3, and it is seen that the changes in the flux distribution are hardly so abrupt as in the case of curve A. The ratio of the maximum to the minimum density of curve D, is 9, while the ratio of the maximum to the minimum ordinates of curve A, is 7. The ratio of the hysteretic loss that would occur in an armature having a core distribution like that of Fig 8, to the hysteretic loss calculated on the assumption of a uniform density in the core, is 1.23.

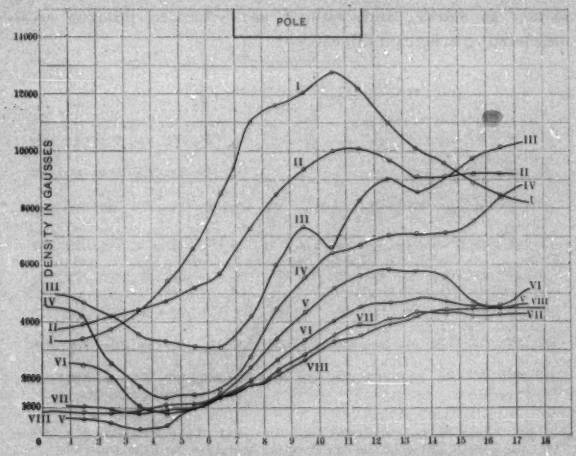


FIG. 12. Curves showing actual densities in the armature core, with one pole at center of the armature, and both field and armature-cross-magnetising coils excited. Airgap, .0613". Field ampere-turns, 1875. Armature ampere-turns, 540.

Therefore there is a difference of 23 per cent. in the experimental case, as compared with 35 per cent. in the calculated case. This difference is due to the fact that the shortest path in Fig. 8 is proportionally longer than the shortest path in section A, of Fig. 1, and to the fact that the armature of Fig. 8 has an infinite radius, and therefore the areas of least density rank equally with the areas of high density in calculating the hysteretic losses, where, as in Fig. 1, the areas of least density are only 54 per cent. as effective as the areas of high density.

The trace of the equal flux paths in Fig. 8, is made by the dotted lines connecting the pole-faces.

The curves of plates 7 and 8 are also very instructive in throwing light upon the matter. They bring out clearly the crowding of the lines of force together as they pass the corner positions of the poles, making the maximum density occur at the sides, rather than at the mid-point between the poles.

The results pictured in the figures so far discussed, were obtained with the two poles of the yoke acting on the armature section as shown, and without any effort to produce cross-magnetizing armature effects.

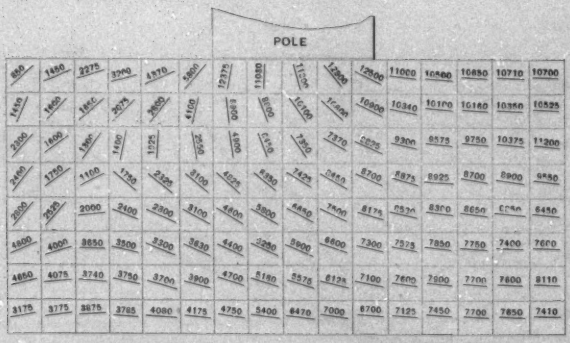


FIG. 13. Chart showing direction and intensity of the armature flux, when one pole is acting at the center of the armature, and the armature is powerfully cross-magnetised. Air-gap .0618". Field ampere-turns, 1875. Armature cross-magnetising turns 1170.

In the succeeding figures the plane of the poles is at right angles to the plane of the armature laminæ. The armature is extended by side bars and a back bar, into a rectangular construction across which the pole yoke bridges. It is this arrangement of the apparatus that is shown in the illustration of the apparatus.

Figs. 9 and 10 show the character of the flux distribution under the pole face when the field coils are acting alone. In this case the symmetrical arrangement of the curves indicates that the flux divided about evenly, and that the return paths to right and left have about the same reluctance. It is noticeable

here as in Fig. 8, that the maximum density occurs at the pole corners, but it falls off very much more rapidly between the poles, as the arrangement of the apparatus admits of only about 14 per cent. of the armature surface being covered by the pole-faces. The bunching of the curves I, II, III and IV, at the sides, and of the curves V, VI, VII, and VIII at the lower corners of Fig. 10 is due both to the presence of the rivets at the sides which hold the armature stampings together, and to the fact, as shown by a special test, that the magnetic joints between the armature

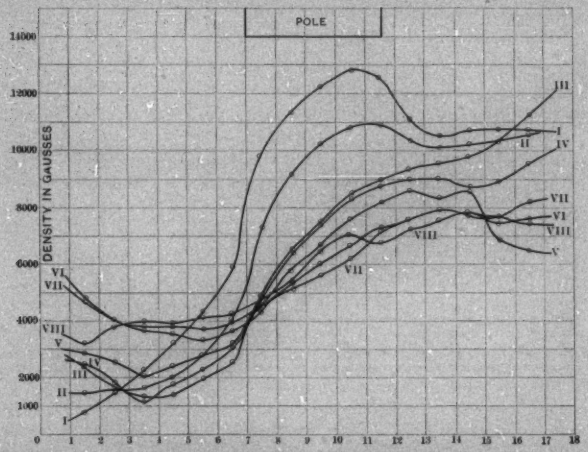


FIG. 14. Curves showing actual densities in the armature, with one pole at its center, and both field and armature-cross-magnetising coils excited. Airgap, .0613. Field ampere turns, 1875. Armature cross-magnetising ampere-turns, 1170.

and end bars was better at the top and bottom than at the middle of the ends of the armature.

In Figs. 11 and 12 the effects of cross-magnetizing currents impressed upon the armature rectangle by means of coils wound around the armature and evenly distributed along its surface are very well exhibited. The armature ampere-turns were arranged to act in one direction only so as to create a field in the armature rectangle without influencing the field yoke. The effect (see Fig. 12) was to markedly distort the core distribution in what

would be the direction of rotation in a dynamo; to weaken the field under the leading pole-tips and to throw the flux towards the bottom of the core. Under the trailing pole-tip just the opposite effect is noticeable, and the special features discussed in connection with section c, of Fig. 1, are all present here. In Fig. 11, the arrows bring out strongly the directions taken by the lines of force issuing from the pole-face. Inasmuch as the pole flux is compelled to separate equally to the right and the left the superposition of the horizontal components of the armature flux upon the pole-field vectors is well illustrated, and a strong similarity can be traced between the effects shown here and those previously calculated.

By doubling the cross-magnetizing effect of the armature ampere-turns all of the effects just noticed were brought out much more strongly. From Fig. 14 it will be seen that the flux density at the lower right hand corner of the armature was raised to two-thirds of the value of the flux in the upper courses, and that on the left hand side the flux has been thrown into the lower courses to so great an extent that the density is four times greater at the bottom of the armature than it is in the left hand upper corner. In this latter case the total flux permeating the armature core is about 2.2 more than that set up by the field ampere-turns acting alone, or the armature ampere-turns set up through the armature rectangle, a field equal to 1.2 times the flux set up in the field coils by the field ampere-turns. The conditions here present are similar to those existing in the older types of dynamo machines in which the field under the leading pole-tips became zero or was reversed by the cross-magnetizing effect of the armature ampere turns.

When the armature ampere-turns were alone excited it was found that the distribution of the flux over a section of the armature core, taken at row number 9 or 10, and at right angles to the direction of the flux, was perfectly uniform.

Purdue University,
Lafayette, Ind.
June, 1889.

Discussion.

Mr. Steinmetz:—This paper of Prof. Goldsborough appears to me a very interesting investigation on the topic of magnetic flux distribution in dynamo electric machines, and I believe a very valuable contribution to our knowledge on these subjects. Obviously the paper does not intend to give final numerical values, but merely to draw attention to some effects existing to a greater or less degree in the armatures of electric machines, consisting essentially in an unequal distribution of the magnetic flux at no loads, and a change of the distribution of flux with changes of loads, both effects acting to increase the loss of power in the armature over that calculated under the assumption of uniform density.

Let us see, however, what conclusions we can draw herefrom. As you know, it is customary to calculate the magnetic core losses in such machines under the assumption of uniform magnetic density, and then to multiply the calculated value by an experimental factor, which makes an allowance for losses in the metallic parts of the armature structure which are near the magnetic field and are necessary for mechanical construction. If now with the constants used in actual machines, the effect consisting in the increase of the core loss due to unequal distribution of flux is considerable, it would follow that with increasing thickness or depth of the armature core, the factor would increase, the distribution of flux becoming more unequal. Experience has shown, however, that those machines in which the core loss is a very large part of the total loss, and can be thus accurately determined, no effect of this kind appears of a magnitude sufficient to make itself felt without special investigation, so that it appears that with the relative dimensions used in most machines the effect is of small magnitude, although undoubtedly existing to some extent.

As well pointed out in the paper, the effect of unequal distribution of flux at no loads, depends on the constants and relative dimensions of the machine, as the depth of the armature core and the distance between the pole corners and the pole arc. Machines with the armature iron extending down to the shaft and poles covering 80 per cent. or more of the pole arc, will show the effect more than machines having shallow armature cores and long distance between the poles, in which latter no notable effect due to an unequal distribution of the magnetic flux should be expected.

Coming now to the second point, the increase of the inequality of the distribution of the magnetic flux with the increase of load, this effect naturally depends on the unequal distribution at no load. In those machines where the flux is uniform at no load, the change in the load will not change the distribution noticeably, while in machines with very irregular flux distribution at no load, considerable changes with the increasing load may be expected.

Furthermore, however, this change of distribution with the load depends upon the relative proportion of armature reaction, that is, magneto-motive-force per pole of the armature, to field excitation; that is ampere-turns per field pole, or rather ampere-turns consumed by the main magnetic flux in armature core, teeth and air-gap.

In machines of large armature reaction, this effect is obviously greater. It is due essentially to the variation of the M.M.F. of the armature which differs from point to point, due to the distribution of the armature M.M.F. over the whole surface of the armature. Thus this effect does not exist at all in those machines where the armature M. M. F., that is the armature conductors are massed in one slot, or two slots in a quarter-phaser, three slots in a three-phaser.

In these machines the resultant of the M. M .F. of the armature and that of the field, and thus the total magnetic flux and the distribution of the magnetic flux in the armature core is the same at no load as at full load, assuming the same induced E. M. F. In these machines you will find no increase of the density or change of the distribution of magnetic flux, outside of a magnetic flux of greater or less magnitude which passes in a local circuit at the armature face across the opening of the slot, due to the armature self-induction, but which does not increase the flux in the armature core, and thus usually introduces a relatively small load loss only.

What I want to bring out is, that this paper while it is extremely valuable, must not be taken as giving exact values, since in this case it might be misleading by letting the reader believe that there is necessarily a very considerable and serious increase of core loss from no load to full load, which is not necessarily the case, as such increase depends entirely on the type and the constants of the machine. But the paper gives, as I said before, very valuable means for further thought and investigation of this feature which has been investigated very little compared with the investigations made in other directions, and for this purpose the paper is of great interest and value.

MR. BLOOD:—I wished to say quite a bit on this subject but I will simply make one or two statements. One is that I find in this connection the difference is not so much as would be expected. It will be found that although between no load and full load there is a large difference in variation in density and movement of the lines; when the amount of iron is considered, the total watts is not what might be expected from the ratio of densities. Another point, the effect is greater where the pole face density is small. Where it is near a hundred thousand lines per square inch the variation does not appear to be so much between no load and full load.

PROF. GOLDSBOROUGH:—I will only say that Mr. Steinmetz has touched upon everything that I might add in connection with the paper. I think you will appreciate the fact that in selecting

the problem, of a machine having a very deep core and 80 per cent. of the armature covered by the poles, I have taken a case which emphasizes the flux distortion. The differences shown between the two methods are not really as important as they may at first appear. For instance, a variation is shown of 45 per cent. in the core loss. But the total hysteresis loss is only one per cent. of the output of the machine, and therefore this increase represents a difference of but a fraction of a per cent. in the efficiency of the generator. It is more a matter of technical interest than of vital practical importance.[1]

THE PRESIDENT:—The next subject is a paper on "Operating Costs of Horse and Electric Delivery Wagons in New York City," by George F. Sever and Robert L. Fliess,

The Chair suggests, that the succeeding paper by E. A. Sperry being on an allied subject, it may be advantageous if the authors are willing, that the discussion on these two papers should be combined.

---

1. Loss in the core below the teeth by uniform density method, 492 watts at full load.

Loss in the core below the teeth by the actual flux distribution method, 830 watts at full load.

Loss in the teeth by both methods, 246 watts at full load. Therefore:—

492+246=738 watts.

830+246=1076.

1076—738÷738=45 per cent.

[Proceedings of Boston meeting will be concluded in November issue.—SECRETARY.]

A paper to be presented at the 137th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22nd, 1899.

[ADVANCE COPY—SUBJECT TO REVISION.]

TEST OF A 300-KILOWATT DIRECT-CONNECTED RAILWAY UNIT AT DIFFERENT LOADS.

BY EDWARD J. WILLIS, M. E.

The test given below is not offered as presenting any novelties either in the manner of the test or in the results attained, but is rather given as a reliable instance to be added to the already accumulated data of this character. It is believed by the writer that where it is possible, it is advantageous that the INSTITUTE should publish reliable data on the water, steam and coal consumption, especially of the direct-connected units in actual commercial operation. In 1896 the writer designed and there was installed under his supervision a steam installation of two 300-kilowatt direct-connected railway units for the Richmond Traction Company. On March 30th, 1897, as superintendent of that road, he had opportunity to test the steam, water, coal consumption and electrical output of one of these units at different loads and it is this data which is listed below.

DESCRIPTION OF UNITS.

Boilers.—One 300-H.P. Campbell & Zell water tube boiler with 3000 sq. feet submerged heating surface.

Engine.—16x30x42 Hoover, Owens & Rentschler horizontal tandem compound condensing engine, double eccentric, 100 R.P.M.

Generator.—300-K.W., 6 pole, steel frame, General Electric railway generator.

Piping.—The piping is practically what is known as standard, being an 8-inch spring from boiler to 14-inch steam-header and 6-inch spring from steam-header to throttle. A short 14-inch exhaust pipe exhausts through a Hartford heater into a Deane jet condenser.

Card Numbers.	Time.	Boiler Pressure.	Receiver Pressure.	Vacuum.	Feed Temperature.	Throttle Temperature.	Injector Temperature.	Overflow Temperature.	Draught Flue Temperature.	R. P. M.	Mean Pressure H.P. Cylinder.	Mean Pressure L.P. Cylinder.	Volts.	Amperes.	Water Feed.	Coal Feed.
1 & 2	12.10 P. M.	108	4 lbs.	25½	190½	343	65	90	360	101	25.76	6.55	550	205		
3 & 4	12.30 "	110	5 "	26½	190	343	65	90	360	101	29.75	6.25	550	210		
5 & 6	12.45 "	118	6 "	26½	190	343	65	91	350	101	24.37	6.60	550	200		
7 & 8	1.00 "	125	7 "	26½	186	350	65	91	320	101	29.50	6.42	550	195		
9 & 10	1.15 "	115	5 "	26½	186	343	65	91	320	101	28.12	6.40	550	192		
Totals.....		576	27	131½	942	1722	325	453	1710	506	137.50	32.22	2750	1002	3469	345
Averages.....		115	5 2-5	26½	188	344	65	91	342	101	27.50	6.44	550	200		
11 & 12	1.19 P.M.	112	7 lbs.	26	186	346	65	97	360	101	39.50	8.60	550	298		
13 & 14	1.36 "	115	8 "	26½	185	346	65	100	380	100	39.00	8.90	550	300		
15 & 16	1.50 "	114	7 "	26¾	183	340	65	97	400	101	40.00	8.37	550	297		
17 & 18	2 05 "	115	8 "	26¾	183	343	65	98	400	101	37.75	8.70	550	300		
19 & 20	2.21 "	113	7 "	26½	183	343	65	98	400	101	41.50	8.25	550	300		
Totals.....		571	37	132½	920	1718	325	490	1940	504	197.75	42.82	2750	1497	4912	455
Averages.....		114	7 2-5	26½	184	344	65	98	388	101	39.55	8.56	550	299		
21 & 22	2.25 P.M.	113	10 lbs.	26¼	185	341	65	111	400	102	48.75	11.45	550	400		
23 & 24	2.42 "	100	6 "	26¾	185	329	65	111	460	100	48.87	11 87	550	400		
25 & 26	2.51 "	115	9 "	26½	185	343	65	111	500	101	46.50	11.15	550	400		
27 & 28	3.10 "	113	8 "	26½	185	342	61	111	500	100	50.37	11.00	550	395		
29 & 30	3.25 "	118	5 "	26½	185	344	61	100	500	100	49.50	10.60	550	393		
Totals		559	38	132½	925	1699	317	544	2360	503	243.99	56 07	2750	1988	5141	575
Averages.....		112	7 3-5	26½	185	340	63	109	472	101	48.80	11.21	550	397		
31 & 32	3.25 P.M.	110	10 lbs.	26	185	340	61	109	530	102	58.87	13.05	550	500		
33 & 34	3.50 "	110	10 "	26	185	340	61	100	540	101	57.00	14.20	550	500		
35 & 36	4.05 "	110	10 "	26	180	339	61	100	560	101	55.75	14.55	550	500		
37 & 38	4.20 "	108	10 "	26	180	339	61	100	580	101	58.87	14.07	550	500		
39 & 40	4.35 "	110	10 "	26	180	340	61	103	580	102	56.25	14.07	550	500		
41 & 42	4.50 "	110	10 "	26	180	340	61	103	580	101	58.25	14.50	550	500		
43 & 44	5.05 "	110	10 "	26	180	340	61	102	580	101	58.50	14.57	550	500		
45 & 46	5.20 "	110	10 "	26	180	340	61	102	580	100	60.25	14.70	550	500		
47 & 48	5.35 "	110	10 "	26	180	340	61	102	580	101	57.00	14.80	550	500		
Totals.....		988	90	234	1630	3038	549	912	5100	908	520.74	130.51	4950	4500	14486	1690
Averages.....		110	10	26	180	340	61	101	567	101	57.86	13.39	550	500		

CALCULATED RESULTS.

LOAD.	POWER. Indicated H.P.	POWER. Electrical H.P.	POWER. Kilowatts.	Evaporation. Water per lb. of coal (actual).	Evaporation. Water per lb. of coal from and at 212° F.	Coal Consumed. Per indicated H.P. hour.	Coal Consumed. Per electric H.P. hour.	Coal Consumed. Per K.W. hour.	STEAM. Per indicated H.P. hour.	STEAM. Per electric H.P. hour.	STEAM. Per K.W. hour.	EFFICIENCIES. Indicated H.P. per electric H.P.	EFFICIENCIES. Electric H.P. per indicated H.P.	EFFICIENCIES. Indicated H.P. per K.W.
300 Amperes.	216	146	110	10.05	10.71	1.45	2.18	2.90	14.8	21.9	29.1	1.48	.68	1.96
300 "	299	220	164	10.8	10.75	1.43	1.94	2.60	15.3	21.9	28.1	1.36	.74	1.82
400 "	373	293	219	8.94	9.53	1.54	1.96	2.63	13.8	17.53	23.46	1.27	.79	1.70
500 "	469	369	275	8.57	9.18	1.66	2.11	2.83	14.95	18.1	24.3	1.27	.79	1.70

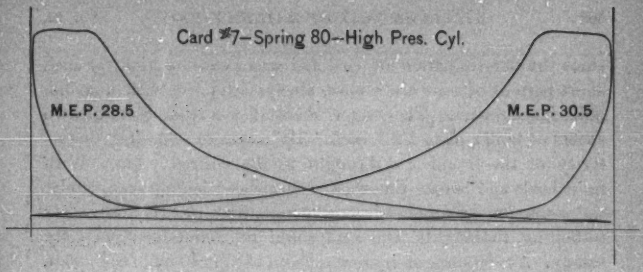
These machines being standard commercial articles, members of the INSTITUTE can readily obtain catalogues, descriptions and detailed blue prints, and it is therefore not thought necessary to burden this paper with lengthy and minute details and data thereon.

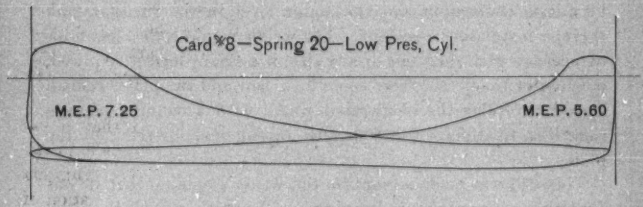
METHOD OF MAKING TEST.

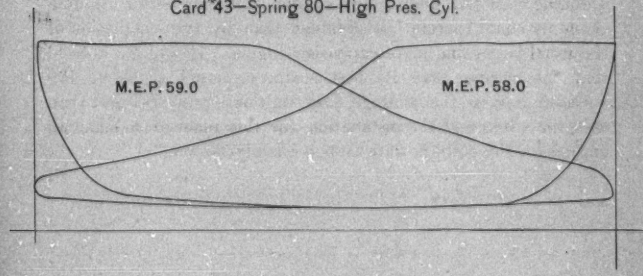
A large water rheostat was provided, capable of handling the full output of the generator, and a Weston ammeter and voltmeter were placed upon the circuit of the generator. By this means the output of the generator could be fixed, maintained and measured at any desired point. The system of piping permitted the feed pump and condenser to be operated by a separate boiler, so that all the steam generated by the boiler passed through the engine. All valves were tested and made tight. A Worthington hot-water meter was thoroughly overhauled before the test and was accurately tested before and after the run. The water and steam consumptions are those given by this meter. The coal fired during the test was Pocahontas run of mine, giving probably 13,000 B.T.U. Draught at grate during run five-eighths of an inch. Indicator cards were taken as nearly every fifteen minutes as possible off both ends of each cylinder and also simultaneous readings of coal, water, electrical output and the other items mentioned in the table. Sample cards are shown below. The object was to determine the steam, water, coal consumption and indicated horse-power of this unit at different loads. The load was as follows: For one hour at 200 amperes, the next hour at 300 amperes, the next hour at 400 amperes, the next hour at 500 amperes, and it was intended to place the load the next hour at 600 amperes, but under such steady load the machine became too warm and instead the load was continued for two hours at 500 amperes.

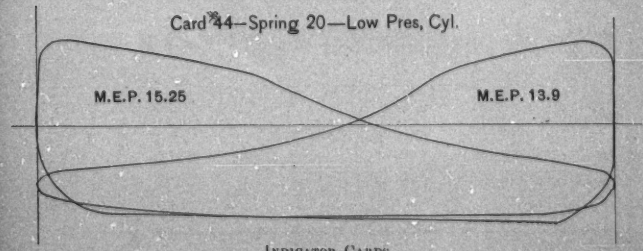
REMARKS.

It is regretted that the point of load could not be carried higher, but it is to be remembered that railway generators are usually designed for fluctuating loads and that such steady loading as given in this test is likely to cause considerable heating. It is further unfortunate for the sake of accuracy that on account of the need of the generator for the operation of the load, the duration of each test could not have been made greater,









INDICATOR CARDS.

since the determination of coal and water consumption for such short periods of time are almost always attended with unavoidable inaccuracies. The water rheostat was composed of two sheets of boiler plate 5′x6′ each. By means of soda the conductivity of the liquid was brought to the desired point. With light loads and before the water commenced boiling completely, there was some fluctuating in amperage, but after the water got to boiling thoroughly, the load could be maintained perfectly steady. At 500 amperes there was about 15 square feet of each plate submerged. The water evaporated by the boiling was replaced by a hose connection and the water level in the rheostat tank thereby maintained constant. The writer would state that in his experience with rheostats of any size, if a steady load is required, it is better to let the water come to a boil and the plates remain steady, replacing the evaporated water with a running connection, than to attempt the continual raising and lowering of the plates.

This test was made to confirm the writer's opinion that it was advisable with railway units carrying fluctuating loads to install a double eccentric under-sized engine, and that better running economy could thereby be obtained than by the installation of the usual larger and more expensive engine. It will be noticed that the engine gave its best steam economy at about 400 amperes, and as the average load on this engine is lower than this, the wisdom of the installation for this plant of so small an engine for the 300 kilowatt units is plainly shown.

PATENT EXPERT.

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